Spin-on-carbon hard masks utilising fullerene derivatives

Conference or Workshop Item

Spin-on-Carbon Hard Masks utilising Fullerene Derivatives

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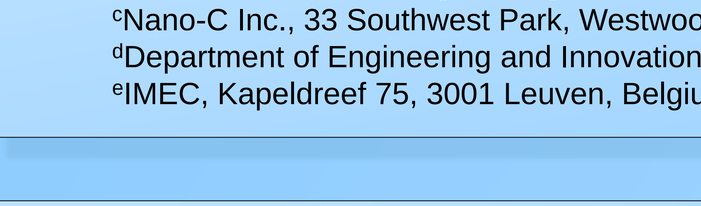
Introduction

The advance of lithographic resolution requires extremely thin photoresist films for the fabrication of '1x nm' structures, to mitigate resist collapse during development. But the use of such thin films will limit achievable etch depths.

Pattern collapse due to aspect ratio

Multilayer hard mask stacks are a possible solution. We have developed a fullerene based spin-on carbon hard mask material, capable of high aspect ratio etching.



Process flow of tri-layer scheme

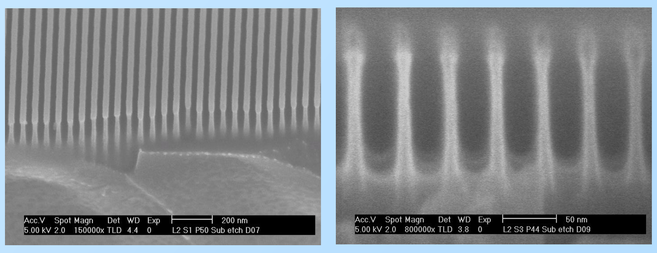
The high resolution image is captured in a thin resist top coat layer and transferred down through the stack to produce high aspect ratio carbon hard mask structures suitable for substrate etching.

Key hard mask properties

Key attributes for hard mask materials include
- Spin coating from standard solvents
- High thermal stability
- Low etch rate in halogen plasmas
- High etch rate in oxygen plasmas
- High resolution patterning (20 nm or better)
- Low "wiggle" at sub-30 nm

The etch resistance of the Irresistible Materials' fullerene based material allows high-aspect ratio plasma etching from a very thin film and at high-resolution.

The materials have low levels of aliphatic hydrogen, which is proposed as a solution to the "wiggling" of features below 30nm, during the plasma etch step to transfer of the features to the underlying layer.
- Wiggling is not observed with IM hard mask materials.

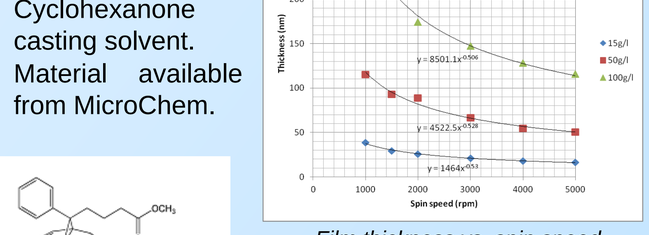


25 nm half pitch &12 nm semi-dense patterns etched into silicon

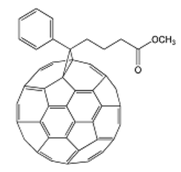
HM100 series fullerene hard mask

Previously reported good results for the HM100 series:

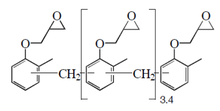
- Cyclohexanone casting solvent.
- Material available from MicroChem.



Film thickness vs. spin speed curves for HM140-350-000 series



Phenyl C_{60} Butyric Acid Methyl Ester

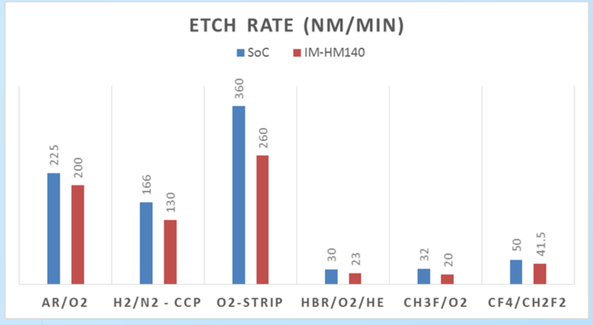


Poly[(o-cresyl glycidyl ether)-co-formaldehyde

Very good etch performance has been demonstrated by researchers at McGill University, Montreal.

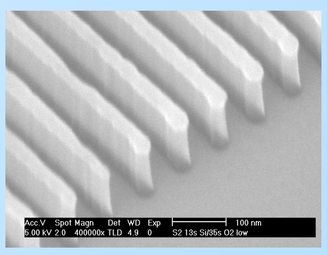
Tests at IMEC show HM140-350-100:
- is more etch resistant than "standard" SoC for the etching amorphous-Si, SiN and SOG
- has an etch performance approaching amorphous carbon (see below).

HM140-350-100 performance

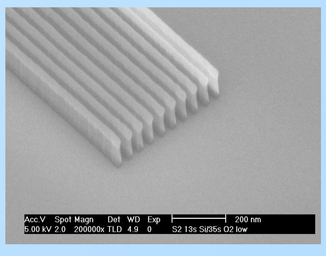


Results of independent etch trials at IMEC

The HM140-350 series formulations use a low cost to produce mixed fullerene multi-adduct derivative, which gives no degradation in the performance as a result of the cost reduction measures.



Sparse 20 nm hard mask features in HM140-350-000

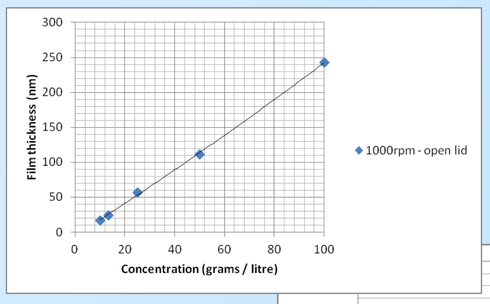


30 nm half pitch patterns in HM140-350-000

New HM340 Hard Mask

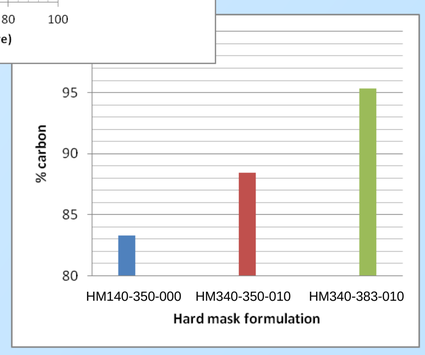
Combining the increased thermal stability and etch resistance of the new 300 series, with increased fullerene to crosslinker ratio.

The material spins from the more acceptable anisole casting solvent. High solubility, >350 g/l allows for a wide range of spun film thickness



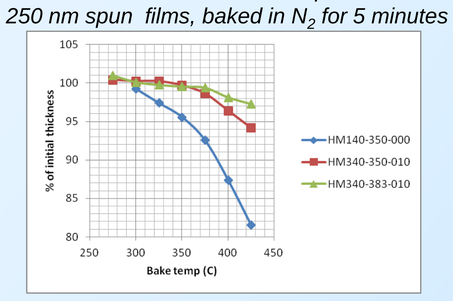
Spun thickness v concentration for HM340-383-010 at 1000rpm

The very high carbon content of the '383' formulation (>95%) should give high etch resistance.

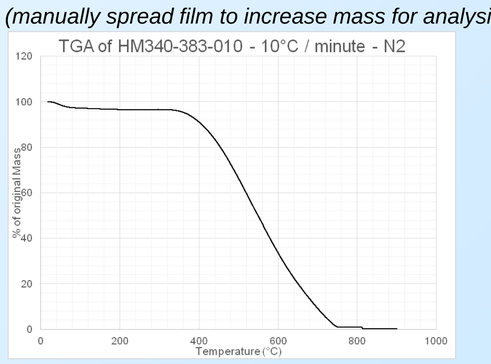


Improved thermal stability

Film thickness loss with temperature
- 250 nm spun films, baked in N_2 for 5 minutes



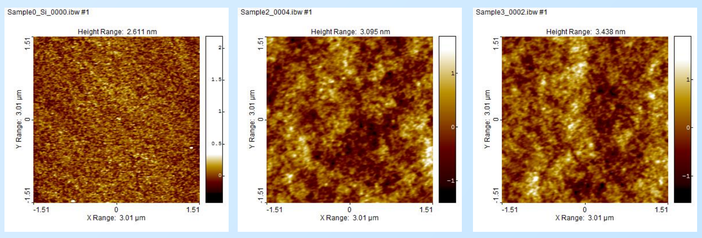
TGA (manually spread film to increase mass for analysis)



The new HM340-383-010, with a higher content of the more thermally stable fullerene derivative and a slightly higher crosslinking bake temperature, has shown improved thermal stability, both in terms of thickness loss with temperature and mass loss with temperature.

Roughness Characterization

Measurements of surface roughness performed by AFM



Bare silicon | *HM340-383-010 50 nm film thickness* | *HM340-383-010 250 nm film thickness*

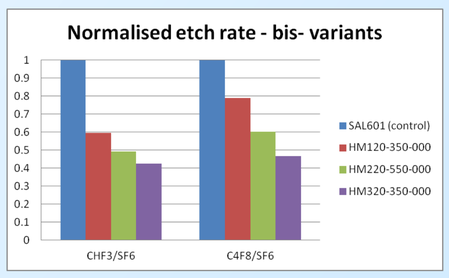
	Bare Silicon	HM340-383-010 50nm	HM340-383-010 250nm
Average Roughness	0.070 nm	0.337 nm	0.333 nm
RMS Roughness	0.094 nm	0.422 nm	0.417 nm
Peak to Valley	2.637 nm	3.294 nm	3.288 nm

Roughness figure for 50 and 250nm thick films are similar, with slightly better results for the thicker film.

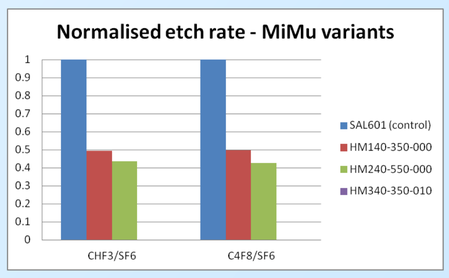
Etch Performance

From the etch performance data, the HM300 series was shown to give better etch performance than the HM100 series, and the HM340 is predicted to have a significantly better etch performance than the HM140.

Hard Mask Formulation	Carbon Content
HM120-350-000	83.95%
HM220-550-000	87.58%
HM320-350-000	88.50%



Hard Mask Formulation	Carbon Content
HM140-350-000	83.79%
HM240-550-000	87.52%
HM340-350-010	88.43%



With the further increased carbon content (from 88.4% to 95.3%), the etch resistance of the HM340-383-010 is expected to be very good. This will be verified in upcoming etch trials.

Summary and Outlook

The use of multilayer etch stacks incorporating carbon hard masks is now essential to enable the semiconductor industry to produce devices at ever shrinking dimensions, particularly given recent developments in three dimensional device architectures, such as FinFET and trigate devices.

These Irresistible Materials' fullerene based hard mask formulations outperform existing state of the art materials across several critical performance metrics, whilst maintaining the advantages of spin-on materials over CVD deposited carbon.

The new HM340-383-010 has a high thermal stability and a very high carbon content, offering high etch resistance.

IM hard mask materials are available from MicroChem, a supplier of specialist chemicals for microlithographic applications (via a non-exclusive license agreement).

Acknowledgements

The Open University
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